Studies on Sonar Clutter and Reverberation

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LONG-TERM GOALS

The long-term goals of this effort are to:

- Assess capability of directional arrays for inversion and reverberation studies
- Characterize acoustic clutter in a manner that will lead to its mitigation
- Improve geo-acoustic parameter extraction from reverberation data
- Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

OBJECTIVES

The objectives of this effort are to:

- Use and continue to collect triplet array data from Five Octave Research Array (FORA) and the NURC arrays, conduct cross frequency correlation studies of scattering features to assess the utility of this technology for reverberation and clutter analysis both in the triplet frequency band (above ~600 Hz) and at lower frequencies.
- Continue validation and improvement efforts on a new reverberation model and investigate physics based clutter modeling.
- Continue work on the automated geo-acoustic parameter extraction technique using reverberation data.
- Operate, maintain and improve FORA hardware and data acquisition systems. Help plan and participate in ocean experiments in support of sea floor scattering, sonar clutter studies and ocean reverberation experiments.

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APPROACH

There is a 4-year Joint Research Program (JRP) with NURC, ARL-PSU, NRL, and DRDC Atlantic, of Canada. It is called Characterizing and Reducing Clutter in Broadband Active Sonar. Experiments are being designed to support the JRP (the Principal Investigator (PI) is a member of this JRP). Recent experimental efforts, called CLUTTER07, took place near the Malta Plateau area in May of 2007 and then a follow-on, CLUTTER09 occurred in May 2009. It was focused on the physics based and the statistical characterizations of acoustic clutter for lower frequency sonars. The FORA was one of two primary receivers for the CLUTTER07 experiment as well as for the BASE07 sea trial that immediately followed it.

The triplet array section at the head of the FORA offers an improved way to study reverberation and scattering in shallow water. Some FORA triplet data was collected in the 2006 Gulf of Maine experiment near Georges Bank, and a much more extensive set was taken in the 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau. In addition, much data has been taken using the NURC array in the same 2007 experiments and in the CLUTTER09 and Boundary 2004 experiments on the Malta Plateau. These data are serving to test and improve the beamforming algorithms and data processing tools needed to better understand reverberation and scattering from towed arrays. The NATO Undersea Research Centre has shown examples of left-right rejections in excess of 15 dB on its triplet array (NURC report SR-329A by D. Hughes, [14]). The PI has verified that similar performance was observed using FORA. Studies on wider band beamforming algorithms are a focus of analysis on the 2007 data sets. It well known that often the same reverberation features can be observed over a wide range of frequencies. Objectives for this task are to continue to correlate the high frequency unambiguous feature information from the triplet data with the lower frequency bearing ambiguous information from line arrays and to define the circumstances under which good cross-frequency correlations exist.

In the past the towed array based inversion algorithms developed by the PI used bearing ambiguous diffuse reverberation data. So results mapped extracted geo-acoustic parameters only in a spatially averaged sense when reverberation was anisotropic. Assessment is continuing on new inversion work using unambiguous triplet reverberation data.

A new faster and simpler range-dependent reverberation model is in ongoing development (together with Dale Ellis of DRDC who is working jointly with the PI) and will serve as the forward model engine for the simulated annealing based inversion scheme already in use. It is expected that refinements to that model will continue under this effort. Examples from the new reverberation model were presented at both the 2006 and 2008 ONR Reverberation Modeling Workshops in Austin, TX and in more detail at the 2007 Underwater Acoustics Measurements (UAM) Conference in Crete and at the NURC 2008 clutter symposium.

WORK COMPLETED

A recent paper by the PI on triplet data analysis presented some directional characteristics of observed clutter and reverberation using triplet arrays [5]. He showed there is usable left right discrimination down to ~600 Hz using the NURC triplet array. Also shown was that the Hughes triplet beamforming algorithm has an upper frequency limitation. In that paper the PI also derived the normalization terms needed to provide calibrated levels out of triplet arrays. More recently the PI has been studying how to improve the Hughes algorithm and has determined that simply expanding the optimum weights term to second order rather than first order destroys the simple linear dependence of the optimum weights on the sines of the roll angles.   After conversations with K. LePage at NURC the PI has concluded that the closed form solution for the weights (eq. 8 of Ref 2) should be used as one way to improve performance. This requires a recoding of the algorithm so work is proceeding on that and the revalidation of the new beamformer. An entirely different technique by Ivars Kirstein at NUWC is also being explored.

Together with D. Ellis, the P. I. submitted two invited journal articles on our Rapid Environmental Assessment (REA) techniques using reverberation. The articles are a compendium of our joint work from 1996 to 2004 and so we felt it was important to document our efforts in a peer reviewed journal [16,17].

Efforts to develop a range dependent normal mode based reverberation model (in collaboration with D. Ellis of DRDC) have continued. Westwood's ORCA [10] is used to generate the eigenvalues and eigenfunctions for an environment and then modifications to Ellis' techniques [11] have been used to build the reverberation model using MATLAB. Results have been submitted (e.g. [6–8]). The most recent efforts have added the time spread and dispersion corrections used by Ellis [11] to the model. The next step will be to implement the adiabatic normal mode formulation for weak range dependent problems. During the past year work was done to improve the short time reverberation estimates by adding leaky modes from ORCA to the algorithm. A sample of this is shown in the next section.

Also in this time period the PI has continued analysis of the Clutter 07 bistatic data sets.

The PI has also spent a fair amount of effort in overseeing the 'care and feeding' of the ONR FORA at Penn State in preparation for the 2010 LRAC experiments with SCRIPPS. This included testing the new FORA acquisition software and understanding and minimizing data latency and synchronization issues in the FORA acquisition programs. Data are now fully synchronized to the GPS time base, and GPS time tags have been added to each data block which now make it possible to track data errors or dropouts accurately. The PI and his technician (J. Dorminy) fully participated in the 2010 LRAC experiment out of San Diego and after one at sea modification the new acquisition software worked flawlessly. As a result of the new software the system is much easier to use and other researchers/students can help operate it now with a much-decreased chance of operator error.

RESULTS

Using the above-mentioned Matlab and ORCA based reverberation model, Figure 1 shows in red, a baseline reverberation vs. time model prediction at 250 Hz for an isovelocity profile and Lambert's Law scattering strength from test prob.11 from the first ONR Reverberation Modeling Workshop. The red curve was generated using the NOGRP model of Ellis and in this case exactly agrees with the PIs Matlab/Orca based model. The black curve was generated using Ellis' time domain model to estimate the very near term reverberation (< 1s) more accurately than the trapped mode solution which can't model the high angle energy well. This new model has been shown to agree with other more accurate models from the workshop. The PI tried adding ORCA's leaky modes to the normal mode formulation and after a bit of work the result is shown as the green curve of Fig. 1. Extrapolating the red curve it can be seen that at .1 s the trapped mode solution is about -85 dB while using leaky modes gives a level of -68 dB and Ellis' more accurate solution oscillates near -62 dB so the leaky mode approximation is a big improvement in the short time reverberation estimates.

At the PI's direction, several improvements were made to the FORA acquisition system (by Programmer G. Ruhlmann). Many small coding errors were corrected last year. Among the most important was the ability to accurately estimate one-way time travel. Previous timing errors were found and corrected. To test it we measured time of arrival of impulses from a pinger system designed by K. von der Heydt of Woods Hole Oceanographic Institute (WHOI) that was attached directly to the FORA. We found a nearly consistent latency of 8 ms ±0.1 ms for the 8 kHz sampling configuration of FORA. In the NPAL 2004 experiment there were errors of at least 0.5 s with no way of correcting them. (This problem had no effect on LFAS experiments because zero time reference starts at the direct arrival of each ping).

This year the acquisition system was completely rewritten. In the course of improving the FORA acquisition system for the PHILEX09 and LRAC10 experiments, GPS time tags have been added for each data block. After one at sea modification the new acquisition software worked flawlessly during the remainder of the LRAC10 experiment just completed and now one-way timing errors are down to approximately 1 ms.

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The new FORA and NURC triplet arrays are exciting tools for ocean acoustic researchers. A wide area-averaged bottom parameter estimation technique such as described above and that utilizes directional reverberation measurements could provide a quick way to estimate bottom parameters and hence give improved sonar performance estimates. Improvements made to the FORA acquisition system have made one-way travel time estimates accurate to within a ms. Time tagging and error logging the data blocks has made it possible to find data dropouts quickly for the first time with FORA.

The CLUTTER09, CLUTTER07 and BASE07 experiments on the Malta Plateau have produced a large quantity of high quality data that will help ONR researchers to understand and eventually mitigate sonar clutter.

TRANSITIONS

Inversion techniques similar to those described above have been applied to select data from recent HEP experiments as part of ONR 6.2 efforts led by Dr. R. Wayland in support of the TAMBDA program at NAWC. In addition, an effort is underway to incorporate the above inversion concepts and reverberation models into a multi-static parallel toolbox – an effort that is being led by J. Joseph at NAWC.

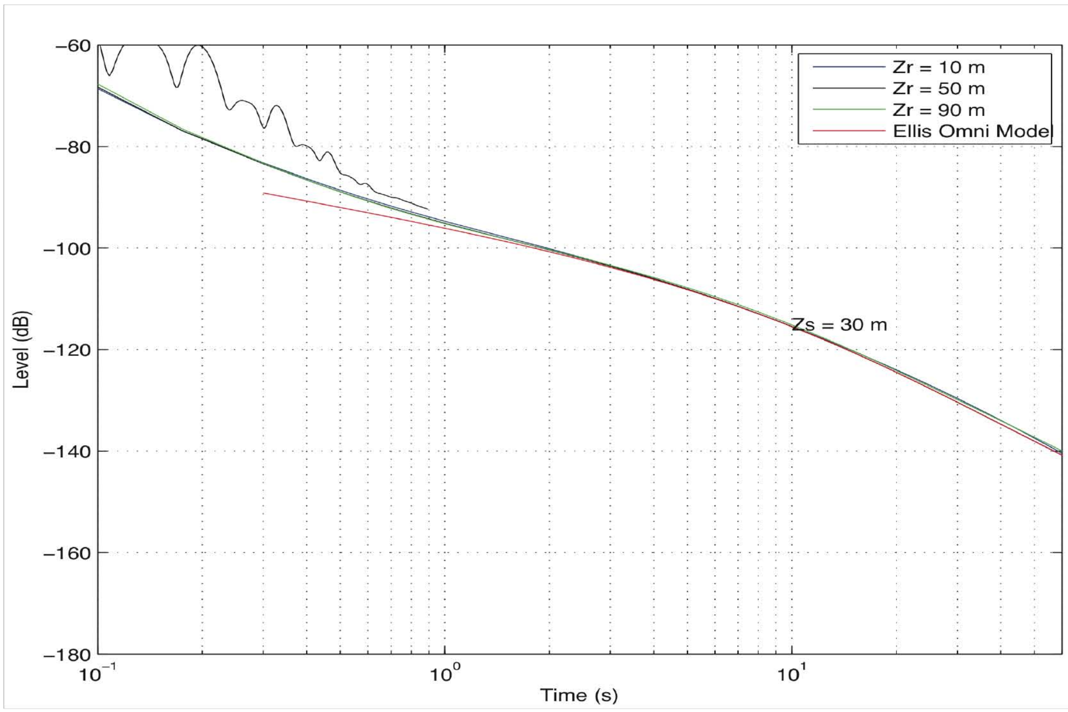

Fig.1. Reverberation model prediction using ORCA with leaky modes for an iso-velocity profile and MacKenzie bottom of test prob. 11 from the first ONR Reverberation Modeling Workshop. Top curve is Ellis' near field time domain computation for comparison. Red curve shows result without leaky modes.

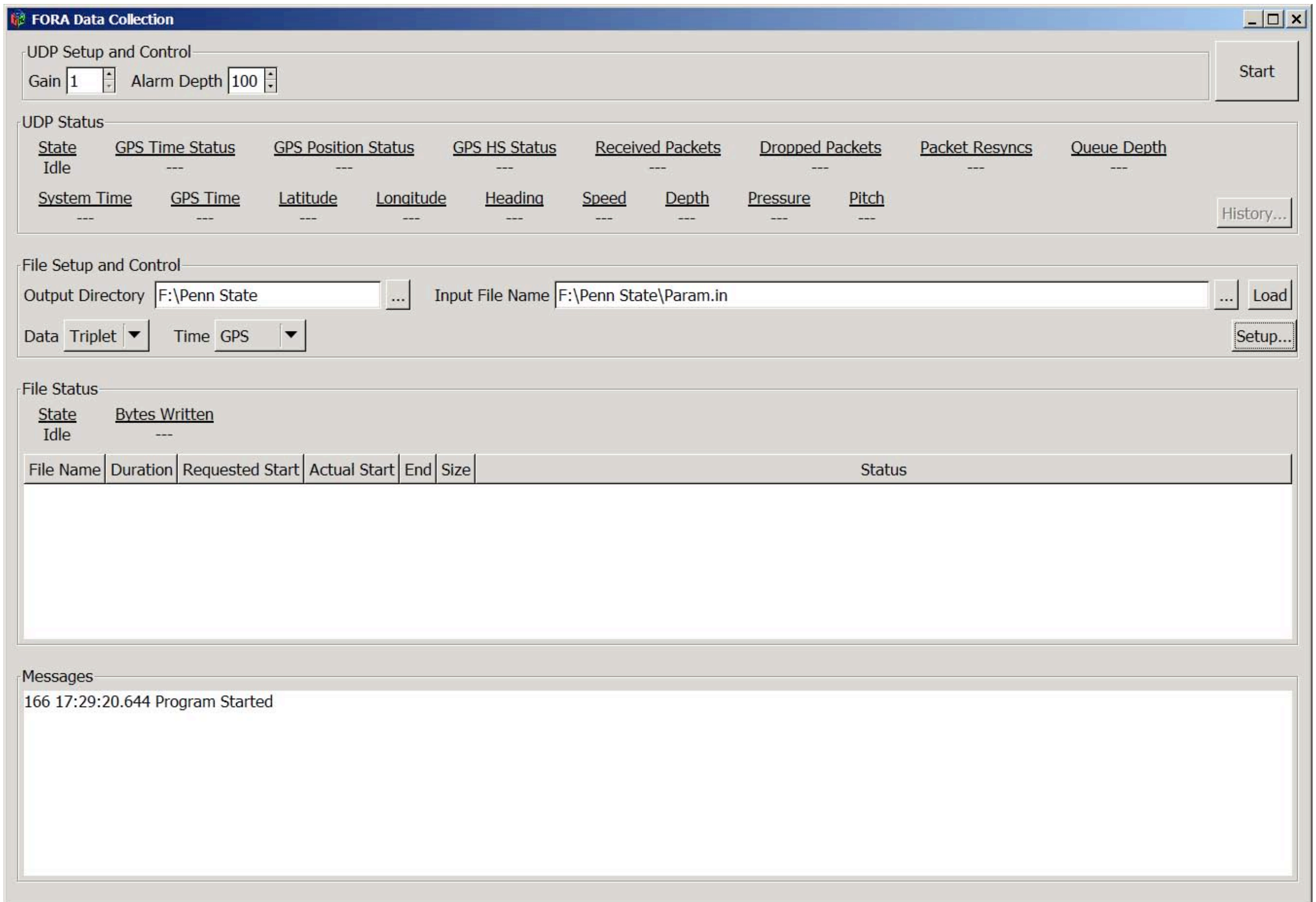

Fig. 2. New FORA GUI courtesy G. Ruhlmann of WaveTech Engineering LLC.).

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